Supporting Volumetric Data Visualization and Analysis by Combining Augmented Reality Visuals with Multi-Touch Input

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Abstract

We present our vision and steps toward implementing a collaborative 3D data analysis tool based on wearable Augmented Reality Head-Mounted Display (AR-HMD). We envision a hybrid environment which combines such AR-HMD devices with multi-touch devices to allow multiple collaborators to visualize and jointly discuss volumetric datasets. The multi-touch devices permit users to manipulate the datasets' states, either publicly or privately, while also proposing means for 2D input for, e. g., drawing annotations. The headsets allow each user to visualize the dataset in physically correct perspective stereoscopy, either in public or in their private space. The public space is viewed by all, with modifications shared in real-time. The private space allows each user to investigate the same dataset with their own preferences, for instance, with a different clipping range. The user can later decide to merge their private space with the public one or cancel the changes.

CCS Concepts

• ***Human-centered computing*** → ***Scientific visualization;*** *Interaction techniques; Synchronous editors;*

1. Motivation

Collaborative interfaces should give users a high degree of control over the interaction, even if the available actions are constrained to maintain the system's coherence [YR12]. Such interfaces should also allow users to work in parallel for better performance. Furthermore, they should provide workspace awareness [GG02] such that each person understands their collaborators' actions. Finally, they should not hide deictic communication during collaboration [GG02], to allow users to interact as they are used to with traditional tools.

Mixed Reality (MR) interfaces [MK94] are the only ones that allow all the users to work in the same space while having a private representation of this space, e. g., visualizing a custom transfer function. MR HMD systems rely on a stereoscopic perspective view that closely matches our normal view of physical space, thus having a high potential for visual data analysis (e. g., [CLP*93, WWG97, BSB*18, HRD*19]), in particular for 3D data visualization. In addition, when using MR devices, users can seamlessly look at focus contents, while also being aware of the surrounding environment—a fundamental benefit for data analysis [DMI*18]. Because Virtual Reality HMDs isolate people from the physical world, AR-HMDs are better suited for collaborative work [BK02]: they allow users to combine virtual contents with traditional physical tools in their collaborative discussion of ideas.

Several research questions arise from the use of AR-HMD-supported data analysis of 3D spatial data. First, we need to ask what type of interaction techniques are best used in AR environments. Taking into account that mid-air gestures fatigue users [HRGMI14], we need to consider dedicated devices to manipulate the workspace, e. g., a multi-touch tablet like in Szalavari et al.'s work [SSFG98]. For such a multi-touch tablet, we need to propose mappings that connect the tablet's 2D input with 3D manipulations of the data and physical space. A second question is how we facilitate workspace awareness for the users, e. g., regarding users manipulating their tablets which are hidden to the others by design. Third, we need to study how we can anchor 2D contents such as annotations or abstract data plots into the AR 3D spatial view. One option is to use an egocentric view, facing each user but preventing clear physical references to these elements. Another option is to use the same physical orientation and position for all, yet at the cost of less ideal orientations for specific people. Forth, we need to understand how we can support users in their deictic communication like physically referring to 3D space locations. Users need to be able to select specific 3D locations in the dataset as well as hybrid 2D/3D locations on annotations placed in 3D space. Moreover, the pointing interaction needs to account for imprecision in pointing and 3D tracking as well as the choice of egocentric or global positioning of the annotations.

With this vision and prototypical implementation, we are working toward ways to address the mentioned questions with regard to the specific interfaces, the interaction design, and ultimately the support of collaborative data analysis. By basing our design on AR visuals we hope to combine the immersion effects of stereoscopic vision with those of interactive data manipulation [BCD*18, LODI16]. The ability to actively walk "through the dataset" and around it, combined with the collaboration that AR interfaces facilitate, can provide a powerful new immersive analytics platform [MSD*18].

2. Vision of the Hybrid Interface

In our vision, we do not want to restrict the use of AR-HMD devices to standalone systems such as AR views combined with traditional workstations [WBG*19]. Instead, we aim to support several data analysts with AR-HMDs to jointly see and interact with the same 3D data representation, shown in a physically correct projection at the same physical space. As we show in Figure 1, collaborators are able to walk around (or through) the dataset, modify its geometry and appearance, and anchor annotations. Such systems must give users awareness about other users' actions. In this example, the user with the *blue* box rotates the dataset. With small number of collaborators, a color encoding can help us to provide the needed awareness by giving enough information about who is performing a specific action. We also envision to use these glyphs to encode additional information about the type and characteristics of the interaction.

We currently use a multi-touch tablet to provide view manipulations as well as to allow hand-drawn sketches, importing images, or writing text. To support 3D actions, we envision to use established AR input techniques such as hand tracking to indicate 3D locations, e. g., placing an annotation [PBWI96] and augmenting deictic actions, e. g., casting a ray from the finger for others to better interpret the intended location. Here both the imprecision of the 3D tracking as well as the issue of reach can be mitigated through the use of virtual elements that connect the physical hands or fingers with the intended 3D location. Moreover, using virtual extensions allows us to use egocentric placements of annotations: while the actual data is placed for all users in the same physical space, the placement of annotations depends on a person's position and the virtual pointing connectors are rendered for each collaborator individually, depending on their egocentric view.

With this setup we can then study the differences between exocentric, egocentric, and hybrid annotation placement, where the latter combines exocentric annotation placement with an egocentric placement of copies. We also want to understand whether people prefer analyzing abstract data representations, e. g., a graphical representation of a statistical analysis of a subset of the data, in the shared AR space or on the personal display space of the tablets. Finally, we plan to investigate how we can support analysts in examining more than one property, e. g., working on both temperature and velocity. Since collaborators may have different fields of expertise, we want to compare two possible interaction designs: (1) a single 3D data representation shown with personal property visualization and (2) a set of a few small-multiple visualizations shown in an exocentric manner, i. e., every collaborator sees all properties. This would thus also allow us to study preferences between exocentric and egocentric mappings [IBG*16] in the specific context of AR visualization.

3. Current Implementation

In our current implementation, we use multiple Microsoft HoloLenses and multi-touch tablets, with a server handling the communication between the devices. One HMD sends the room's 3D scan result to the server which is then broadcast to the other HMDs. We support the loading of multiple datasets (e. g., from climate research), which may possess multiple properties in VTK file format. We use a ray-marching algorithm in a shader to render the data, with each cell encoding its normalized (i. e., between 0.0 and

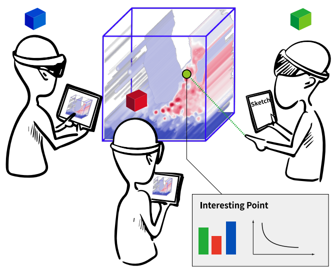

Figure 1: *Vision: each tablet facilitates 3D interaction and 2D annotation. Users are represented by colored glyphs floating above them. If a user manipulates the dataset on their tablet, the dataset is highlighted with their color* (blue *here*)*. Pointing cues and 3D position selections are augmented with virtual rays and spheres seen by all users.*

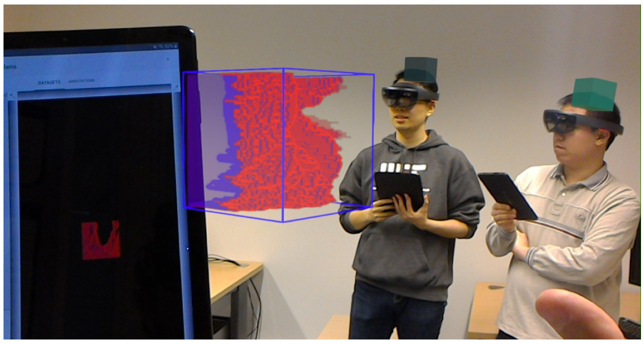

Figure 2: *Current setup: three users wear a HoloLens paired with a tablet to analyse water salinity. The tablet on the left shows an orthographic view of the dataset and allows 3D manipulations.*

1.0) gradient and raw values. We currently use the Gaussian Transfer Function [KPI*03], with $center = scale = (0.5, 0.5)$. The tablets display an orthographic view of the selected dataset and support 3D translation, rotation along the vertical axis and uniform scaling based on Yu et al. FI3D technique [YSI*10]. When translating or scaling, the tablet's virtual camera is animated, passing from an egocentric to an exocentric view of the dataset matching the paired HMD's viewpoint. Figure 2 shows a screenshot of the system.

Our next steps include the public and private view spaces management, 3D placement of annotations and data analysis, and volumetric visualization tweaks such as the transfer functions parameters. Once the system is complete, we plan to study its practicability. First, we want to study the current navigation mappings between the tablet and the data representation based on existing methods, e. g., touch-based (e. g., [CDH11, YSI*10]) or tangible or hybrid mappings (e. g., [BIAI17, BRLD17]). Second, we plan to study the manipulations and the transitions between the private and the public spaces, the human behaviours in these spaces and the needed workspace awareness to provide. Third, in these two spaces, we want to compare the combination of exocentric and egocentric placements of data representations and annotations. Finally, we want to compare collaborative hybrid multi-touch tablet/AR-HMD setup with other collaborative setups such as table-top displays for 3D visualizations.

4. Conclusion

With our studies we work toward a better understanding of immersive analytics tools [MSD*18], specifically targeted at inherently 3D spatial datasets but also integrating representations of abstract data aspects. We apply guidelines from work from the CSCW domain to support a collaborative data analysis environment.

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